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THE EFFECT OF A RICKETS-PRODUCING DIET ON THE LEARNING ABILITY OF WHITE RATS

A DISSERTATION SUBMITTED TO THE GRADUATE FACULTY IN CANDIDACY FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PSYCHOLOGY

By
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THE EFFECT OF A RICKETS-PRODUCING DIET ON THE LEARNING ABILITY OF WHITE RATS[1]

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I. INTRODUCTION

The purpose of this study was twofold: first, to compare the maze-learning ability of albino rats upon a rickets-producing diet with that of rats on an adequate dietary régime, and second, to determine whether any difference which might be noted was transitory or persistent. Maze learning was tested during the period of active rickets, when clinical symptoms were unmistakably present, and again after recovery had taken place. Retention of the first maze habit was also tested.

Previous to the beginning of this work, in July, 1926, no experimental studies had been reported in the field. Shortly thereafter Anderson and Smith (1) published their study of the effect of qualitative and quantitative stunting upon maze learning in rats, in which they reported that during the period of stunting the dwarfed animals were superior to the controls in speed of learning, but this superiority was diminished after a period of realimentation. As to errors, the control and qualitatively stunted groups were superior in relearning to the quantitatively stunted animals, and on learning a new maze both experimental groups made more errors than the controls. The original grouping was made on the basis of time records in a preliminary maze test, but the error records were not equated, and the

[1] Studies from the Institute for Juvenile Research, Chicago, Series C, No. 171.
A thesis submitted in partial fulfilment of the requirements for the doctor's degree from the University of Chicago. The project was undertaken as a part of the research program of the Institute for Juvenile Research, Chicago, and was financed by that institution. The second part of the work was done in the Psychology laboratory of the University of Chicago.

qualitatively stunted group had a larger initial error score than the others. The authors suggest inequality of motivation as a possible explanation of their results.

Maurer and Tsai (5, 6) depleted rats of the vitamin B complex during the nursing period, and report that they required more trials and time and made more errors in learning a maze than control animals. Their analysis of their data shows remarkable consistency in all criteria, but an examination of the individual records shows considerable overlapping. The statistical procedure followed by these authors in the interpretation of their data is unorthodox, and leads to the reporting of two very different figures as representing the reliability of each single group difference. The authors also state that the degree of depletion was subject to variation but they give no indication as to the extent in terms of clinical symptoms, although they claim results conclusively due to vitamin B deficiency.

Gesell (2) refers to a preliminary report of the New Haven Rickets Investigation and Demonstration under the auspices of the Federal Children's Bureau and Yale University, in which he states that the retardational effect of rickets in children is "less than is commonly supposed and is transient in character."

II. METHODS AND PROCEDURE

The rats used in the experiment were bred in the laboratory from pure albino stock. At the age of thirty to thirty-five days, when they had attained a body weight of 55 to 65 grams, littermates of the same sex and the same weight were assigned to three groups—normal controls, rachitics, and underweight controls. Two Carr mazes were used, referred to as maze I and maze II. Maze I tested learning during the period of active rickets, and maze II after recovery. Retention of maze I was tested three months after the initial learning.

A slightly modified McCollum diet was used for the colony. It consisted of rolled oats and ground whole wheat each 25 per cent, ground whole yellow corn 23.5 per cent, casein 15 per cent, Klim 10 per cent, calcium carbonate 0.5 per cent, and sodium chloride 1 per cent. It was used throughout the experiment,

with weekly supplements of lettuce and cabbage, and occasional allotments of liver. This diet, without the supplements, was used for the normal and underweight controls during the learning of maze I and for all rats during learning of maze II and retention tests on maze I. Rickets was produced by means of the McCollum diet No. 3143 (3), and later by the Steenbock-Black diet No. 2965 (7).

After assignment to the three groups the normal controls were allowed to eat their fill of the stock diet; the rachitic rats were fed as much as they would eat of the rickets-producing diet; and the underweight controls were given just enough of the stock diet to keep their bodyweight equal to that of their rachitic litter-mates. All rats were weighed daily and the underweight animals were fed individually. During this period the rats were fed in the food box of the maze occasionally just after weighing, and for three days preceding the first learning trial they were fed exclusively in the maze. After twenty-eight days on the respective diets the rats were put into maze I for 1 trial the first day and 5 trials a day thereafter until they had learned the maze to a criterion of 10 consecutive errorless runs. During the learning period the rachitic rats were given food in their cages for three hours to insure their obtaining enough to promote growth, since rachitic lesions tend to heal during low food intake or starvation. The frequent anorexia encountered with the McCollum diet led to the introduction of the Steenbock-Black diet for the second half of the work. The underweights were still maintained at the level of their rachitic litter-mates, and the normals were put on a maintenance ration while learning maze I.

At the beginning of the maze learning all of the rachitic rats had developed unmistakable clinical symptoms of rickets as shown by the underweight, the bone deformities, the tottering gait, the side-to-side movement of the hind legs in walking, and the peculiar hop while running. Some of these animals developed such gross bone deformities that these persisted to the end of the experiment even after more than three months on an adequate diet.

After the mastery of maze I the rats were put on a realimenta-

tion diet for twenty-eight days. All rats were then fed the stock diet ad libitum, and to the food of the rachitic rats was added 1 per cent of cod liver oil. After realimentation the rats were tested on maze II for persistent effects of inanition. The procedure was the same as in the case of maze I, except that all animals were kept on a maintenance diet during the second maze period. After the second maze was learned the animals were put into stock cages with no separation of groups, and treated as stock animals. Three months after the learning of maze I all animals relearned this maze, running 5 trials a day to a criterion of 10 errorless runs.

The work may conveniently be divided into two parts. Part I was carried out in the laboratory of the Institute for Juvenile Research and part II in the laboratory of the Department of Psychology of the University of Chicago. A few of the rachitic rats in part I were fed the Steenbock-Black diet, but their records were more nearly like those of the rest of the rats in this laboratory, so the data were pooled with those obtained with the McCollum diet. In part II only the Steenbock-Black diet was used. In both parts of the work the procedure followed was the same, namely: (1) establishment of good growth in all rats, (2) division into an experimental and two control groups by litter-mates equated as to sex and weight, (3) production of rickets in the experimental group and quantitative inanition in one control group, (4) testing immediate effects of rickets and quantitative stunting on maze learning, (5) realimentation, (6) testing of delayed effects of rickets and quantitative stunting on maze learning, and (7) relearning of a maze habit established three months previously.

The number of rats used and their distribution are shown in table 1. The variation in the numbers in the various groups is due to the fact that in some cases there were more than 3 usable rats from the same litter, so the extras were assigned at random to the various groups. In no case was any rat used which did not have a litter-mate in each of the other groups. If one rat was lost and had no litter-mate in the same group, the corresponding rats in the two other groups were also removed.

Daily weight records were kept on all rats, but unfortunately those for part I were accidentally destroyed. Average weight curves for the rats of part II are presented in figures 1 and 2. These are not continuous curves, but represent growth by weekly intervals during the qualitative feeding period and the period of realimentation, and the weight of the rats at the beginning and end of each maze-learning period. These learning periods are not divided into regular time intervals because the rats varied in the number of days spent in mastering the mazes. It will be seen that while on the first maze the underweight and rachitic rats were receiving somewhat more than enough food for maintenance, and that the normals were on approximately maintenance ration. It is also evident that the rachitic rats did not as a

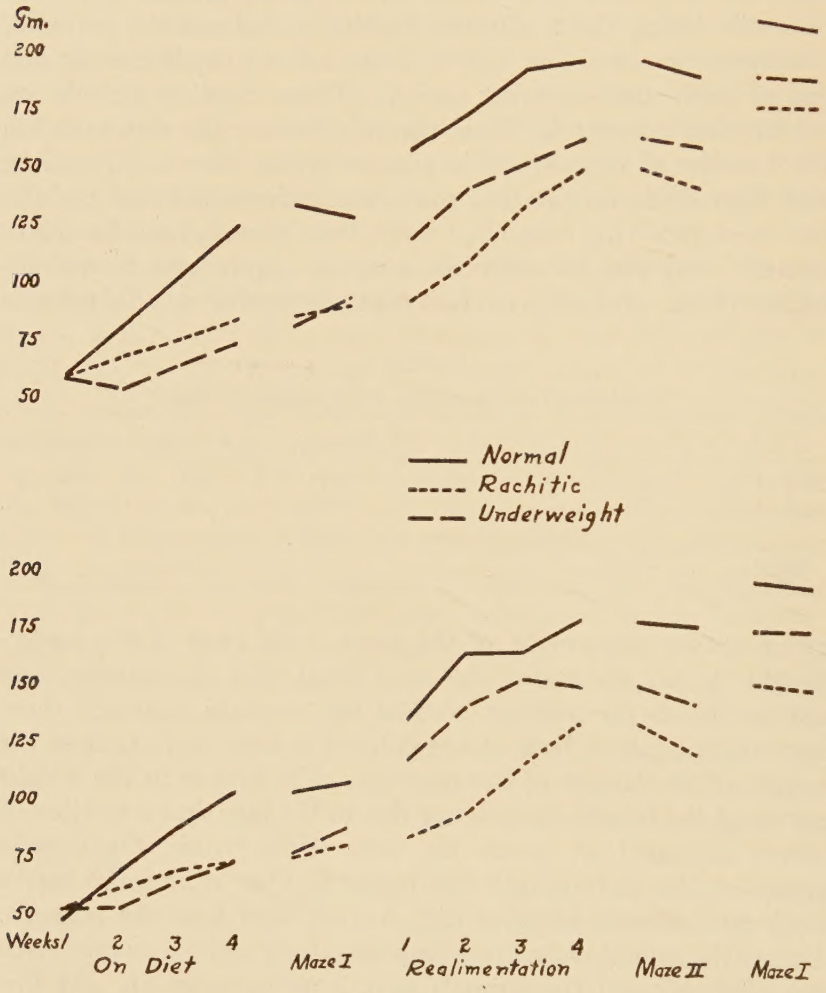
TABLE 1

Number and distribution of experimental animals

	NORMAL	RACHITIC	UNDERWEIGHT
Part I	27	22	24
Part II	28	24	29
Total			154

group attain the weight of the normals or even of the underweights before the end of the experiment, and the underweights did not reach the average level of the normals, although there were individuals in both of the stunted groups that attained the weight of the largest of the normals. The breaks in the weight curves of the female animals are due to the fact that a number of litters appeared at about the same time within the several groups. The underweight rats began to litter during the fourth week on the realimentation diet, a week later than the normals. Among the rachitic rats litters appeared later and the curves were not affected until the animals were learning maze II. At this time there were litters among the underweights and the rachitics. These animals were not actually on a lower food intake than the others, but the appearance of young accounts for the greater loss of weight by the underweight and rachitic females than by the

normals. Males and females were kept in the same cages throughout the experiment, only the groups being separated because of the difference in diet.



FIGS. 1 AND 2

FIG. 1. WEIGHT RECORDS OF EXPERIMENTAL RATS—PART II. MALES
FIG. 2. WEIGHT RECORDS OF EXPERIMENTAL RATS—PART II. FEMALES

III. RESULTS

1. Learning records. Table 2 shows the trials and time required and the errors made by all groups in both parts of the experiment in learning maze I. In part I both dietary groups made better mean learning records according to number of trials required than did the normals, although the median scores of the normals and underweights are similar. In part II, however, the underweights required more trials than did the normals, and the rachitic animals maintained only a slight superiority. All the rats of part II required fewer trials to learn maze I than those of part I. Reasons for this will be discussed later.

TABLE 2

Trial, time, and error scores on maze I

	TRIALS		TIME		ERRORS	
	Median	Mean	Median	Mean	Median	Mean
Part I:						
Normal	77.0	87.1	4,112	5,061	239.0	251.4
Rachitic	65.5	68.8	11,446	12,153	149.5	174.4
Underweight	74.0	74.8	2,251	3,744	183.5	206.5
Part II:						
Normal	39.0	43.7	2,110	2,222	99.5	121.4
Rachitic	35.5	39.1	5,435	6,624	84.5	86.5
Underweight	63.0	55.3	1,732	1,894	128.0	126.2

The underweights in both parts of the study learned maze I in less time than the other two groups, in spite of the fact that in part II they required more trials. The rachitics of both parts, however, required more than twice as much time as the normals, along with their lower trial scores in both cases. The rachitics did, of course, have a considerable motor handicap, but this alone could hardly be considered sufficient to account for the large difference in time required. A rat with its hind legs so paralyzed that they were useless in running and had to be dragged through the maze could still make the run in twice the amount of time required by the controls. Very few rats reached this stage of

motor involvement, and most of those which did so died before the end of the experiment, so that their records are not included

FIG. 3. TIME LEARNING CURVES—PART I. MAZE I

in the data. Even for the rachitic rats the time curves in figures 3 and 4 show a drop, although they should rise if physical

exhaustion were a factor. But in most cases the rachitic rats proceeded leisurely, stopped often, made few retracings, and explored little in the blinds. The time ratios are remarkably

FIG. 4. TIME LEARNING CURVES—PART II. MAZE I

constant in the two parts of the experiment. The underweight rats required 74 per cent of the time of the normals in part I and 85 per cent in part II; the rachitic rats 240 per cent in part I and 298 per cent in part II.

The error records show that the rachitic rats maintained their superiority over the two other groups in both parts of the experiment. The underweights learned with fewer errors than the normals in part I but showed no difference in part II.

Reliabilities of the differences among the groups in trials, time, and errors may be seen in table 3. The greatest and most consistent difference is to be found in the time scores, which were always by far the largest for rachitic rats. This group, however, tends to excel when error scores are compared.

TABLE 3

Reliability of differences among groups in trials, time, and errors in learning maze I $\left(\frac{D}{P.E._D}\right)$

	TRIALS	TIME	ERRORS
Part I:			
Normal—rachitic	3.10	−7.62	4.75
Normal—underweight	2.08	2.10	2.47
Underweight—rachitic	−1.15*	−8.49	1.61
Part II:			
Normal—rachitic	0.84	−7.58	3.29
Normal—underweight	−3.20	2.05	−0.41
Underweight—rachitic	5.09	−8.21	4.65

* A negative value denotes that the score of the second member of the pair was greater.

2. Delayed effects. Table 4 gives the data for all criteria of learning for maze II in both parts of the experiment. After realimentation most of the differences in maze learning were eradicated. Table 5, which gives the reliabilities of the differences for maze II, shows clearly that most of the discrepancies among the groups have been ironed out by this time. In part I there were no significant differences in time and error criteria, although the rachitics required the fewest trials. In part II the rachitics took more trials than the other groups and the underweights again learned in less time than the others. This may be due to a carry-over of maze habits formed in the learning of maze I. However, it seems likely that if the three groups could

be brought to the same degree of nutritional stability at one time there would be no significant differences in any of the criteria of maze learning. This would be a difficult thing to accomplish without changing other conditions of the experiment, in view of the fact that some of the rats suffered more severe rachitic

TABLE 4

Trial, time, and error scores of realimented rats in learning maze II

	TRIALS		TIME		ERRORS	
	Median	Mean	Median	Mean	Median	Mean
Part I:						
Normal	73.0	66.4	1,756	1,848	92.0	100.7
Rachitic	53.5	54.7	1,362	1,802	90.0	96.0
Underweight	65.0	68.1	1,505	1,946	95.0	106.2
Part II:						
Normal	19.0	19.9	629	690	39.0	38.4
Rachitic	23.0	23.5	612	720	38.0	36.1
Underweight	15.0	18.3	423	506	34.0	35.4

TABLE 5

Reliabilities of differences among groups in learning maze II $\left(\frac{D}{P.E._D}\right)$

	TRIALS	TIME	ERRORS
Part I:			
Normal—rachitic	1.89	0.24	0.02
Normal—underweight	−1.29	−0.40	−0.05
Underweight—rachitic	2.16	0.52	0.07
Part II:			
Normal—rachitic	−1.81	−0.44	0.79
Normal—underweight	0.81	3.41	1.11
Underweight—rachitic	−2.46	−3.76	−0.24

lesions than others and degree of underweight varied considerably also. The findings here appear quite in agreement with the conclusion reported by Gesell in connection with the New Haven study on babies, namely, "it appears that rickets, like other forms of malnutrition, alters and depresses the behavior output

but does not greatly curtail or arrest the basic maturation of the nervous system."

3. Relearning. Perhaps the most interesting findings of the experiment were those obtained on retention tests made on maze I three months after the original learning, and with the

TABLE 6

Trials and errors in relearning maze I

	TRIALS		ERRORS	
	Median	Mean	Median	Mean
Part I:				
Normal	6.5	7.0	9.0	8.9
Rachitic	16.0	19.5	22.0	20.5
Underweight	36.5	39.5	36.0	47.8
Part II:				
Normal	3.9	4.6	5.5	7.8
Rachitic	8.0	10.8	8.5	16.3
Underweight	8.0	12.3	16.0	20.1

TABLE 7

Reliabilities of differences among groups in relearning maze I $\left(\frac{D}{P.E._D}\right)$

	TRIALS	ERRORS
Part I:		
Normal—rachitic	−5.14	−4.30
Normal—underweight	−9.03	−6.80
Underweight—rachitic	4.78	4.45
Part II:		
Normal—rachitic	−3.44	−2.34
Normal—underweight	−5.07	−4.90
Underweight—rachitic	0.68	0.91

interpolation of another maze between learning and relearning. From the end of the learning period on maze II all rats were kept in stock cages, without separation of groups or sexes. Preliminary feeding was given on the maze as usual, and the rats were run 5 trials a day to a criterion of 10 successive errorless

runs. Tables 6 and 7 show the trial and error records and the reliabilities of the differences among groups. In these tests the normal rats excel in both parts of the experiment. The rachitics made more than twice as many errors as the normals, and the underweights more than five times as many in part I, and both underweights and rachitics made more than twice as many as the normals in part II. In the first part the rachitic rats were superior to the underweights in relearning but in the second part they made similar records.

4. Effects of distraction.[2] An examination of the data presented above reveals the following discrepancies:

a. All rats make decidedly better learning scores on the same maze in part II than in part I.

b. The relative improvement in part II is less for the underweight animals than for the rachitics and the normals.

c. The error score for normal rats in part I is greater than that for underweight rats, but in part II there is little difference, and that very slightly in favor of the normals.

d. The retention scores of the normal animals are decidedly the best in both cases, although in learning these animals appear to be inferior to one or both of the other groups.

e. The underweight animals show greater improvement in relearning in part II than the rachitics and the normals.

To attribute these inconsistencies to chance is to avoid the issue. The measurements are facts, and the discrepancies are so great that other factors must be operating. As a matter of fact, in the first part of the work, because of the crowded condition of the laboratory, the rats were subject to a number of distractions in the form of noises from shop activities and from other animals quartered nearby. These noises undoubtedly had their effect upon all of the animals, although the underweights displayed the least amount of noticeable behavior disturbance. They ran very fast, made few stops, and tended to repeat each time the route of the previous trial; thus they showed a tendency to make more stereotyped errors than did the other animals. The normals and

[2] The writer wishes to thank Dr. N. R. F. Maier for valuable suggestions in working up this part of the data.

rachitics, on the other hand, often had their routine quite disrupted by the distractions. The rachitics would stop and proceed again only after a long wait, and would often take more time for the rest of the day's runs, with or without an increase in errors. The normal rats were also considerably disturbed, and for a number of trials following would take more time or make more errors, or both. The absence of this distraction in part II will easily account for the first inconsistency, that all rats made better scores in the second part of the experiment than in the first.

The other inconsistencies are not so simply explained, however. That rats make errors in learning situations which are not due to lack of learning but are a function of inattention and variability has been demonstrated by Maier (4). It is possible that in this situation also many of the errors were due to factors other than inequality in learning ability, and the task becomes one of determining differences in error scores resulting from unequal learning ability and those resulting from other influences. If errors are due to lack of learning resulting from different learning ability in the various groups, then a comparison of the mean error scores for the three groups at any point during the learning process should show the groups in the same relative positions with respect to each other, provided there was no marked difference in the shapes of the learning curves for the three groups. If one group is more subject to errors from influences other than lack of learning, the scores of this group will probably fluctuate during the course of the learning and cause this group to vary its position from time to time in relation to the other groups. To determine the possibility of such an occurrence the daily mean error scores were arranged in three groups, position 1 being given to the group making the largest number of errors for the day, position 2 to the group occupying the middle position, and position 3 to the group making fewest errors for the day. These figures were then translated to percentages for convenience.

Table 8 shows the percentage of days on which each group occupied positions 1, 2, and 3, with respect to the mean number of errors for the group. Thus, in part I, the normal animals made

most errors on 60 per cent of the days, least on 30 per cent of the days, and were intermediate on 10 per cent of the days. The records of the rachitic animals also are distributed among the three positions. The underweights held position 1 only 5 per cent of the time, and for 75 per cent of the time they were in position 2. But it is evident that all groups fluctuated among the three positions, whereas in part II only the normals were so distributed, the rachitics and underweights here occupying only two positions each. In other words, the normal rats were relatively more variable in both situations than the other two groups, and the rachitic rats were more variable than the underweights in part I. Such an analysis, of course, gives no information as to absolute variability.

TABLE 8

Positions of groups in daily mean error scores, maze I

	PART I			PART II		
	1	2	3	1	2	3
Normal	0.60	0.10	0.30	0.20	0.55	0.25
Rachitic	0.35	0.15	0.50	0.00	0.25	0.75
Underweight	0.05	0.75	0.20	0.80	0.20	0.00

We have here, then, a learning situation in which, under usual laboratory conditions, normal rats show greater variability than rachitics and underweights, and the two latter groups hold their relative positions quite stably. When the same learning situation is transferred to an environment involving the further factor of distraction, both the normal and the rachitic rats are more variable than the underweights. What effect would this situation have upon the usual measures of learning ability? We have already stated that the presence of distraction in part I would cause the learning scores of all animals to be inferior to those in part II, where the distraction was not present. Now we find that distraction as measured by relative group variability was less for the underweight rats than for the others, and we find that the relative improvement of scores in part II was less for the underweight rats than for the other groups, which takes

care of the second inconsistency. The lesser improvement in this group will also account for the third point, that there was little difference in errors between the normals and underweights in part II.

If this analysis is reasonable, it should follow that a similar comparison of the groups in learning maze II should show little difference among the groups in distractability, since all rats were presumably in a state of nutritional equilibrium while learning maze II. Table 9 shows what occurred. As might be expected, all groups fluctuated among the three positions in both parts of the experiment.

The above analysis shows that the normal rats are not actually inferior in learning ability, as an uncritical examination of the

TABLE 9

Positions of groups in daily mean error scores, maze II

	PART I			PART II		
	1	2	3	1	2	3
Normal	0.23	0.27	0.50	0.39	0.38	0.23
Rachitic	0.35	0.42	0.23	0.31	0.31	0.38
Underweight	0.42	0.31	0.27	0.31	0.31	0.38

results might suggest. Under the circumstances we should not expect inferiority in relearning. On the other hand, since there is no less ability to learn, but errors are made because of other factors, the normal rats are required to make more runs in order to achieve the arbitrary criterion of learning. In so doing they undoubtedly get a certain amount of overtraining which should be beneficial in relearning the same maze later. As a matter of fact, they excel in the relearning tests in both parts of the experiment. Moreover, in part I the rachitic animals showed a decided superiority over the underweights in relearning which was not borne out in part II. The rachitic animals likewise showed greater disturbance due to distraction in the first part, and therefore were subjected to more over-learning. Whether all the difference in relearning is accounted for by over-training is open to question, particularly since the difference in favor of the

normals is so great, but such an explanation does take care of the fourth inconsistency, that a group of rats apparently inferior in learning ability is superior in retention. It also accounts in part, at least, for their superiority in relearning.

There remains still the fact that there was difference in incentive in the various groups during the learning of maze I. The underweight rats were much more eager for food than the others, and made their runs in much less time. This in itself may be a reason for their lesser relative distractibility. Upon relearning the maze later they acted more like the normal animals that they were at that time and tended to explore more. Then, if they did not reach the criterion of learning in the first few trials, they were again subject to the variability of normal animals, and prolonged their trials probably beyond the point of actual learning. The normal animals, on the other hand, reached the criterion of learning in a very few trials, and thus their actual superiority in relearning may be less than the figures would indicate.

On the whole, it is difficult to conclude that there are differences in learning ability among normal, rachitic, and underweight rats. Differences in learning scores according to the established criteria do exist, but the repetition of the work under well and poorly controlled conditions brings out other influences which in either situation alone are obscured. Errors are considered the best criterion in maze learning, but certainly any one error cannot be considered as equivalent to any other error, and until we have some method of distinguishing types of errors, maze-learning of this kind is not an adequate technique for testing small differences in learning ability among groups.

IV. SUMMARY

1. The immediate and delayed effects of rickets on maze learning were tested in two laboratories, and with two rickets-producing diets, using albino rats as experimental animals.

2. The performance of the rachitic rats was compared with that of normal rats and with that of rats which were kept underweight by the reduction of the calorie intake.

3. Rats with active rickets learned the maze in fewer trials than normal rats, and with fewer errors, but they consumed much more time in learning. The increase in time was out of proportion to the amount of motor involvement produced by the rachitic syndrome. That the increase in time was not due to the underweight involved in the disease was evident from the fact that the rats kept at a corresponding degree of underweight without rickets learned the maze in much less time than the normal rats. They also required more trials and made more errors than the rachitics.

4. After realimentation differences in maze learning among normal, rachitic, and underweight rats for the most part disappeared. Whatever effect may have been produced by the disease did not persist long beyond the period of active rickets, even though bone deformities were still present.

5. Apparent differences in maze-learning among the three groups are questioned because of various inconsistencies. These inconsistencies are explained when a measure of variability due to distraction is introduced.

6. Underweight animals are less subject to variability due to distraction than are normal and rachitic animals. Normal rats seem to be most easily distracted.

7. If differences in learning ability do exist in normal, rachitic, and underweight animals, the usual maze technique is inadequate for their demonstration.

8. Relearning of a maze three months after the original learning shows normal rats decidedly superior to rachitic and underweight rats, but whether this is an actual difference in retention or due to some other factor or factors is an open question.

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